**TITLE PAGE**

**Manuscript Title:** Higher fuel prices are associated with lower air pollution levels

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## ABSTRACT

Air pollution is a persistent problem in urban areas, and traffic emissions are a major cause of poor air quality. Policies to curb pollution levels often involve raising the price of using private vehicles, for example, congestion charges. We were interested in whether higher fuel prices were associated with decreased air pollution levels. We examined an association between diesel and petrol prices and four traffic-related pollutants in Brisbane from 2010 to 2013. We used a regression model and examined pollution levels up to 16 days after the price change. Higher diesel prices were associated with statistically significant short-term reductions in carbon monoxide and nitrogen oxides. Changes in petrol prices had no impact on air pollution. Raising diesel taxes in Australia could be justified as a public health measure. As raising taxes is politically unpopular, an alternative political approach would be to remove schemes that put a downward pressure on fuel prices, such as industry subsidies and shopping vouchers that give fuel discounts.

**Keywords**: air pollution, policy, fuel, vehicles, taxes

## 1. Introduction

Traffic emissions are the major source of air pollution in most urban areas. High levels of traffic pollution are associated with multiple serious health problems, including myocardial infarction,[1] stroke,[2] asthma[3] and preterm birth.[4] Traffic emissions are a major contributor to ambient outdoor particulate matter pollution, which is the ninth leading risk factor in the global burden of disease.[5] Vehicular fossil fuel combustion also makes a substantial contribution to global warming.[6]

Reducing traffic-related air pollution is difficult as many people contribute to its creation and policies that aim to reduce vehicle usage are met with resistance from the powerful car lobby.[7] Congestion charges (where fees are charged in an effort to reduce vehicle use) are generally unpopular with the public and have had mixed results in terms of reducing in traffic-related air pollution.[8] Policies that improve fuel and vehicle standards do improve air quality,[9] but take time to have an impact.

Traffic pollution has many parallels with cigarette smoking as a public health issue,[7,10] including that reducing the health impacts can be achieved by reducing consumption. One proven method of decreasing cigarette consumption is to raise prices. We were interested in whether higher fuel prices had a positive effect on air quality. In economics this is known as "price elasticity" and higher fuel prices do reduce vehicle numbers,[11] but no research has shown if the reduction in vehicle numbers is large enough to impact on air quality. We examined whether higher fuel prices in Brisbane, Australia, were associated with reductions in traffic-related air pollution.

## 2. Materials and Methods

Brisbane is the capital of the state of Queensland and is its most populous city (2.2 million people). We assessed the association between daily fuel prices and daily air pollution levels in Brisbane from July 2010 to June 2013. We examined the most recent three years as this gave us sufficient statistical power, with a greater than 90% power to detect a 10% short-term change in the selected air pollutants for a 10 cent change in price.

We used average daily pollution data from two monitoring stations that are the city's most directly exposed to traffic emissions. These stations are near the city centre and near to major roads and freeways carrying 50,000 to 130,000 vehicles per day (see Appendix).[12] Both stations are subject to traffic emissions from all wind directions. We examined the following air pollutants that are markers of traffic-related air pollution: carbon monoxide, nitrogen oxides ($NO_x$) and particulate matter.[13] For particulate matter we examined both $PM_{2.5}$ ($< 2.5$ µm) and $PM_{10}$ ($< 10$ µm).

We obtained average daily price data across Brisbane for unleaded petrol and diesel. Approximately 75% of vehicles in Brisbane are fuelled by unleaded petrol, and 20% by diesel, which covers 95% of vehicles.[14]

### 2.1 Statistical methods

We were only interested in the short-term association between fuel price and pollution. Long-term changes in pollution levels are due to other factors such as improved combustion technologies, and long-term changes in fuel prices are due to multiple factors including international exchange rates. We removed these long-term trends and the seasonal variation in daily pollution and prices using a natural spline with three degrees of freedom per year.[15]

We assumed a linear association between daily fuel price and pollution, and allowed a potentially delayed association, as fuel bought today can be used several days later. We assumed a maximum lag of 16 days between prices and pollution. This was based on local data using: an average fuel tank of 68 litres, an average fuel consumption of 13.8 litres per 100 kilometres, and average daily distance travelled of 31 kilometres.[14] Using these figures an average full tank would need refilling in 15.8 days.

We present the results as a percentage change in pollution levels, using the change from the overall pollution averages for 2010 to 2013.

### 2.2 Missing pollution data

There were some missing pollution data (see Appendix). We imputed missing daily data from a monitoring station by exploiting the strong correlations between: i) multiple pollutants from the same station (e.g., CO and $NO_x$ at station A), and ii) the same pollutant at other stations (e.g., CO at station A and CO at station B). We tested the accuracy of this imputation by randomly deleting 30 observations and comparing our predicted and observed values. The Rsquared values for these predictions were all above 70% for pollutants that were used (see Appendix). If a pollutant had more than 5% missing data at a given station then we did not use it.

## 3. Results

Higher diesel prices were associated with statistically significant short-term reductions in $NO_x$ and CO (see Figure). The percentage reductions from the lowest to the highest diesel price were around 30% for $NO_x$ and 70% for CO. There were no statistically significant associations with unleaded petrol prices, as the 95% confidence intervals in the Figure contained 0% for all prices. $PM_{2.5}$ and $PM_{10}$ levels were not associated with either diesel or petrol prices.

## 4. Discussion

Our results show that concentrations of some traffic-related air pollutants were greatly reduced in the short-term when fuel prices were high in Brisbane. Higher prices reduce the number of vehicles on the road which directly reduces traffic emissions, and fewer vehicles means less congestion which can further reduce emissions. Higher fuel prices may also encourage more people to use public transport, which would also lower pollution levels.

We did not observe an effect of fuel price on $PM_{2.5}$ or $PM_{10}$. This was consistent with local emission inventories and source apportionment studies, which suggest traffic emissions contribute a much greater relative proportion of CO and $NO_x$ compared to particulates.[16,17]

Pollution levels were dependent on diesel but not unleaded petrol. Local emission inventories suggest that petrol vehicles are the major source of CO and $NO_x$.[16] The disparity between our results and the emission inventory could reflect to the regional scale of the inventory (hundreds of kilometres) versus our focus on a highly localised scale (less than 10 metres), with pollution monitors located immediately proximate to emission sources. While diesel vehicles make up only 20% of the vehicle fleet in Brisbane, overseas studies have shown they can emit a disproportionate share of the total traffic emissions of $NO_x$ concentrations when measured near the source, such as in road tunnels.[13,18,19] Studies have also shown that diesel emissions can be reduced by 60–80% on weekends due to reductions in road freight, and this change has been associated with lower $NO_x$ levels.[20,21] It is therefore plausible that changes in diesel price have an appreciable impact on air pollution due to the reduction in diesel vehicles on the road.

Another possible explanation for the strong association with diesel is that drivers who are the most price-sensitive are those with the least fuel efficient and most polluting vehicles. This could be because those vehicles most affected by price are medium and large diesel trucks, which are a major source of traffic-related air pollution,[21] or older passenger vehicles and four-wheel drives.

Our results imply that tax increases to fuel could be used to improve the nation's health by reducing the adverse health effects associated with traffic-related air pollution and increasing the use of public and active transport.[22,23] Current Australian government taxes on fuel are based on energy content with diesel and petrol in the "high-energy" category with a tax of 38 cents per litre, with a lower 23 cents per litre for "mid-energy" content fuels such as ethanol. Based on these numbers we postulate creating a "very high-energy" category for diesel with an increased tax of 53 cents per litre (based on the 15 cents per litre difference between the "mid" and "high" categories). Using our modelled results (Figure) this increase in tax would be associated with a 40% reduction in daily CO and 17% reduction in daily $NO_x$. Applying these reductions to studies of the health effects of air pollution in Brisbane would mean an approximate 2% reduction in daily emergency hospital admissions for children and adults.[24,25] These percentage risks are small, but they have a large public health impact because pollution exposure occurs every day. Assuming a 2% reduction over the whole year would mean around 200 fewer emergency admissions in adults and 15 in children. It is important to note that there are many other health benefits to reducing pollution exposure that we have not quantified, including improved lung function, improved birth outcomes (including birth defects), reduced general practitioner visits and reduced mortality.

Tax increases for vehicles rarely garner public support and any Australian politician that recommends increasing the price of fuel is likely to be voted out. A better political approach would be to remove schemes that put a downward pressure on fuel prices, such as industry subsidies and shopping vouchers that give fuel discounts of up to 40 cents per litre. Interestingly, the fuel discounts scheme in Australia was limited to 4 cents per litre in January 2014 because of concerns about market competition. This creates a small natural experiment concerning whether this policy change reduces future traffic pollution levels.

We cannot be sure how the public would react to a controlled tax increase or subsidy removal, and their reaction may not realise the pollution reductions shown here due to uncontrolled price increases. Long-term reductions in traffic pollution levels could occur if people were motivated to stop low priority journeys, or combine the activities from two or more car journeys into one in order to save fuel. Some people may also be motivated to make a positive change to their behaviour, such as using an alternative method of transport.

Our results imply that policies that encourage smarter vehicle use using a financial incentive could be successful. This could include lower taxes for zero or less polluting electric and hybrid vehicles, lower public transport prices, and tax incentives to encourage cycling (the UK, USA and Netherlands all have government financial incentives to encourage cycling). However, such policies would not lower pollution levels if the major sources of traffic pollution are vehicles for which there are no currently no reliable clean alternatives, such as heavy goods vehicles that need to travel long distances and have no electric alternative.

### 4.1 Other policies

Australian governments in the last 30 years have committed to improving air quality, and policies have been discussed and implemented with the aim of lowering vehicle emissions.

There have been multiple national restrictions to vehicle fuel and emission standards since the 1990s that have been credited with improving air quality standards.[26] An analysis of long-term trends in Australian cities from 1996 to 2011 showed that carbon monoxide levels have decreased by 33–79% and sulphur dioxide levels by 0–95%, but that particulate matter and ozone levels have been largely unchanged.[27] In late 2013 tighter pollution standards came into law for new vehicles which aimed to cut particulate matter emission by 90%.

A cleaner car rebate scheme was suggested in 2010 to support people to replace their old cars for cleaner vehicles using a $2000 rebate.  $394 million was initially set aside (which would have been enough to replace almost 200,000 vehicles), but the policy was abandoned in 2011 as the money was redirected to disaster relief.

Comparing the national costs and health benefits of these policies with a higher fuel price was beyond the scope of this paper.

### 4.2 Conclusion

We should be cautious about our results in terms of generalisability, as we only examined the association between pollution and fuel price in one city. We should also be cautious because we have only shown an association between pollution and short-term changes in price, but a long-term change is what is really needed to improve health. Getting usable data on the long-term impact of major air quality policy changes is very difficult because studies are likely to have a small sample size (even if multiple cities were involved), and long-term changes in air pollution are associated with multiple other factors. We should also be cautious about assuming the improvements in pollution due to a short-term price increase would apply to a permanent price increase due to a tax or subsidy removal. Our evidence examining a short-term change had sufficient statistical power to show an association, and provides evidence that air pollution can be reduced by raising the cost of using vehicles. Improving air quality is a high priority for many cities around the world. Any discussion of policy options to improve air quality must consider the costs of producing pollution and whether they are too low.

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## Figure legends

Figure: Changes in percentage air pollution levels associated with changes in fuel prices in Brisbane, 2010–2013. The 0% level on the y-axis is the pollution level for the reference price of 144 cents for diesel and 141 cents for petrol which were the average prices during the study period.

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